

APEX sub-mm monitoring of gamma-ray blazars*

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So far, no systematic long-term blazar monitoring programs and detailed variability studies exist at sub-mm wavelengths. Here, we present a new sub-mm blazar monitoring program using the APEX 12-m telescope. A sample of about 40 γ -ray blazars has been monitored since 2007/2008 with the LABOCA bolometer camera at 345 GHz. First light curves, preliminary variability results and a first comparison with the longer cm/mm bands (F-GAMMA program) are presented, demonstrating the extreme variability characteristics of blazars at such short wavelengths.

1. INTRODUCTION

“Blazars” comprise a sub-class of radio-loud AGN showing a broad-band, double-humped spectral energy distribution (SED). They differ from all other types of AGN chiefly because of their extreme phenomenological characteristics such as the extreme and broad-band flux density and polarisation variability, high degree of polarisation, fast superluminal motion and almost uniquely broad-band emission characteristics including a bright and highly variable component of γ -ray emission [11].

Despite many efforts over the last decades, several key questions still remain unanswered in fully understanding the blazar phenomenon. For instance:

- which are the dominant, broad-band emission processes involved (synchrotron self-Compton/inverse-Compton)?
- which mechanisms drive their often violent, broad-band variability? (e.g. relativistic shocks, colliding plasma shells or changing geometry due to helical/precessing jets; see e.g. [8] [6] [4])
- what is the typical duty cycle of their activity?

- does the γ -ray emission originate from the base/foot-point of the jet or further out in the same shocked regions as the radio cm/mm/sub-mm band emission?

Observations that can ascertain whether a relationship exists between the γ -ray and radio emission will be important for the effort to answer these questions.

Consequently, variability studies furnish important clues about the size, structure, physics and dynamics of the emitting region making AGN/blazar monitoring programs of uttermost importance in providing the necessary constraints for understanding the origin of energy production. Here, observations at short-mm/sub-mm bands are crucial, as they probe the innermost nuclear region and provide the important direct link between the longer wavelength radio bands and the more energetic IR/optical to γ -ray regimes.

Until now, there has been no systematic long-term blazar monitoring program and detailed variability study at sub-mm bands. Consequently, little is known about the variability characteristics of AGN at sub-mm bands. Important parameters which need to be determined are e.g. the variability amplitude and time scales and how the variability is related to other bands, e.g. correlation strengths and time lags. The knowledge of the variability behavior at sub-mm bands will thus better constrain the modeling of the variability and spectral evolution in the synchrotron branch of blazar SEDs.

In this framework, we initiated a blazar monitoring program using the APEX sub-mm telescope. The

*Based on observations with the Atacama Pathfinder EXperiment (APEX) telescope in Chile. The APEX telescope is operated by the Max-Planck-Institute für Radioastronomie, the European Southern Observatory and the Onsala Space Observatory.

aim of this effort, which is part of the F-GAMMA program [5] [2], is to perform the first long-term systematic study of blazar variability characteristics at sub-mm wavelengths. Here we present first light curves and some preliminary results on the relative variability for our sample of sources. Details including the full first years of data and analysis will be presented in Fuhrmann et al. (in prep.).

2. APEX observations with LABOCA

The APEX 12m sub-mm telescope is located at 5100m altitude on Llano Chajnantor, Chile. The observations are obtained with the LABOCA camera [10], which consists of 295 channels arranged in 9 concentric hexagons. LABOCA has a total field of view of 11.4 arcmin and allows observations in the 870 micrometer (345 GHz) atmospheric window (bandwidth: 60 GHz).

The quasi-regular observations of our program started in 2008 and are performed during several dedicated MPI, Swedish and ESO APEX LABOCA time-blocks per year. In addition, we are aiming at denser, more regular sampling through the regular and frequent pointing observations performed at APEX since 2007 using our sources in the framework of other projects and APEX technical time. Observations within the F-GAMMA program are typically performed in *spiral observing mode* with a raster of four spirals of 20 or 35 seconds of integration each, depending on the source brightness at 345 GHz. At each run, skydip measurements for opacity correction and frequent calibrator measurements are performed. The number of observations per source range from 2 to 177.

3. The Sample

At APEX, a sub-sample of 25 prominent, famous, frequently active and usually strong γ -ray blazars from the F-GAMMA sample is observed together with a sample of 14 interesting southern hemisphere γ -ray AGN. The complete list of APEX monitored sources is given in Table 1.

4. FIRST RESULTS: Sub-mm variability properties of gamma-ray AGN

Some examples of source light curves are shown in Figure 1. All the monitored sources, except one, show excess variability (over that expected from measurement noise). The exception is Mkn 501, which we exclude from the following variability analysis. For all the remaining 38 sources the χ^2 -analysis gives a

Table I List of monitored sources. Source class and 2FGL associations are taken from the second LAT AGN Catalog [1].

2FGL Name	Source Name	Source Class
J0210.7-5102	PKS 0208-512	Blazar
J0217.9+0143	PKS 0215+015	FSRQ
J0237.8+2846	4C +28.07	FSRQ
J0238.7+1637	PKS 0235+164	FSRQ
J0303.5-6209	PKS 0302-623	FSRQ
J0339.4-0144	PKS 0336-01	FSRQ
J0403.9-3604	PKS 0402-362	FSRQ
J0423.2-0120	PKS 0420-01	FSRQ
J0530.8+1333	PKS 0528+134	FSRQ
J0538.8-4405	PKS 0537-441	BLLac
J0854.8+2005	OJ 287	BLLac
J0909.1+0121	J0909+0121	FSRQ
J1058.4+0133	4C +01.28	BLLac
J1057.0-8004	PKS 1057-79	BLLac
J1159.5+2914	J1159+292	FSRQ
J1221.4+2814	W Comae	BLLac
J1229.1+0202	3C 273	FSRQ
J1256.1-0547	3C 279	FSRQ
J1315.9-3339	PKS 1313-333	FSRQ
J1325.6-4300	Cen A	RG
J1428.0-4206	PKS 1424-418	FSRQ
J1457.4-3540	PKS 1454-354	FSRQ
J1504.3+1029	PKS 1502+106	FSRQ
J1512.8-0906	PKS 1510-08	FSRQ
J1626.1-2948	PKS 1622-29	FSRQ
J1635.2+3810	4C +38.41	FSRQ
J1642.9+3949	3C 345	FSRQ
J1653.9+3945	Mkn 501	BLLac
J1733.1-1307	PKS 1730-13	FSRQ
J1751.5+0938	PKS 1749+096	BLLac
J1958.2-3848	PKS 1954-388	FSRQ
J2056.2-4715	PKS 2052-47	FSRQ
J2157.9-1501	PKS 2155-152	FSRQ
J2158.8-3013	PKS 2155-304	BLLac
J2202.8+4216	BL Lac	BLLac
J2225.6-0454	3C 446	FSRQ
J2232.4+1143	CTA 102	FSRQ
J2253.9+1609	3C 454.3	FSRQ
J2258.0-2759	PKS 2255-282	FSRQ

probability of less than 0.1% that the observed variability is due to measurement noise. In a preliminary variability analysis, without taking the time sampling into account, the modulation index was calculated as $m = 100 \times rms/mean$. For most sources the modulation index is in the range 10 - 50 %, but there is a tail in the distribution which extends up to $m = 90\%$ as shown in Figure 2. The mean and

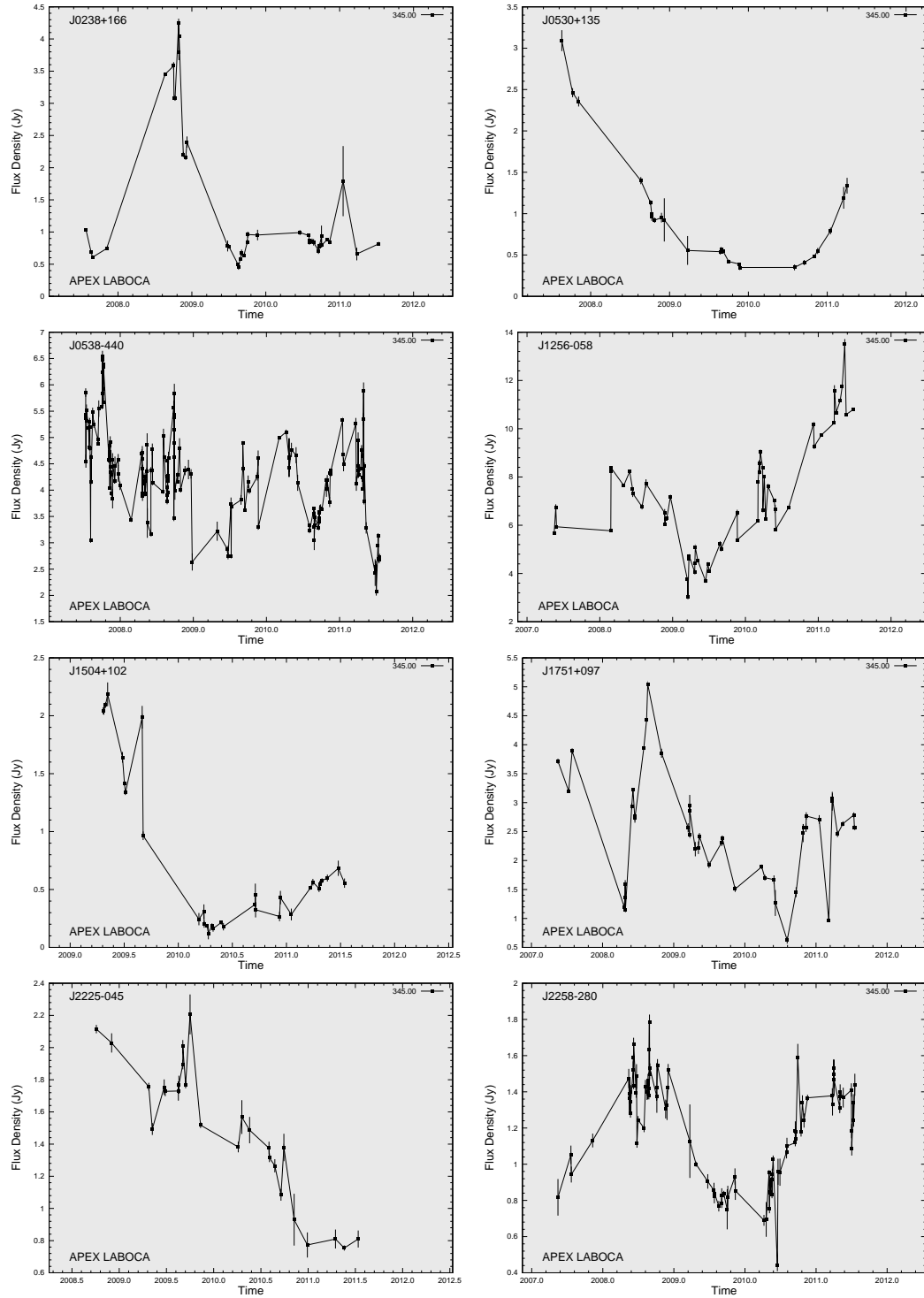


Figure 1: Examples of long-term light curves for several blazars monitored at sub-mm wavelengths with LABOCA on the APEX telescope. All sources show strong variability in this band.

median modulation indexes are 37 and 31% respectively. A number of sources show variations by a factor of 10 or more between minimum and maximum flux. This is significantly larger than at the longer cm- and also short-mm bands. The variability is in general also faster and more directly correlated with the high energy emission[7]. This is most likely an effect of opacity/synchrotron self-absorption increasing towards the longer radio wavelengths and indicates that the sub-mm emission regions are more co-spatial with the optical/ γ -ray ones.

In an analysis of the spectral evolution observed by the cm/mm F-GAMMA program [3], it has been shown that the radio flares and multi-frequency variability can be well described by only two physical processes: (i) achromatic variability (possibly related to helical or precessing jets) or (ii) evolving synchrotron flares or shocks inside the relativistic jets (as described in e.g. [9]). In such synchrotron scenario of evolving AGN outbursts, the flux-density variability first appears at higher frequencies (IR/optical/UV/X-ray) and then propagates through the spectrum towards longer wavelengths. The formation and evolution of shocks is expected to start at high synchrotron frequencies during their growth stage where the synchrotron self-absorption peak moves to lower frequencies while the peak flux and variability amplitude is increasing (mm/sub-mm bands) up to the plateau stage, followed by a subsequent decay stage (cm-bands). Here, the variability in the sub-mm band is expected to be much more pronounced and faster than at longer cm-radio bands[12]. This was confirmed to 1 mm wavelength by the earlier observations (Fuhrmann et al. in prep.): the mean strength of variability (modulation index) steadily increases from 9.5% at 110 mm to 30% at 1 mm. Our new LABOCA observations imply that this trend continues into the sub-mm band. According to the three different regimes of shock evolution (growth, plateau, decay), such continued increase (or flattening) would then indicate that, on average, flares reach their plateau/decay phase at sub-mm bands well before they do at cm bands. A more extensive analysis and discussion of the variability properties will be presented in a forthcoming paper.

Acknowledgments

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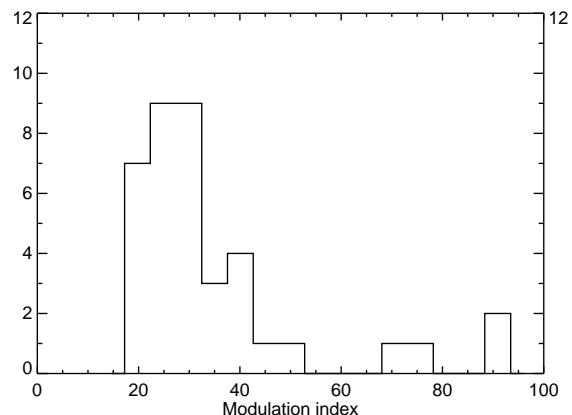


Figure 2: The distribution of modulation index for the 38 variable sources (excluding Mkn 501 for which the variability is not significant). The bins in modulation index are 6 units wide.